The Vortex Ring State Fallacy

By Col. R. E. Joslin, USMC

A CH-53E in a steep approach to a pinnacle suddenly has a high rate of descent and hits hard in the landing zone. The mishap investigation indicates the helo had sufficient power to hover out of ground effect.

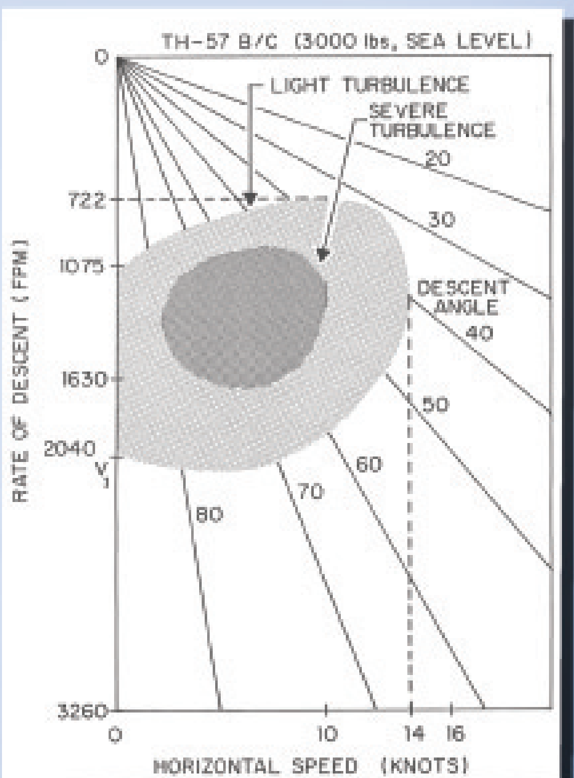

Fig.1 Vortex Ring Diagram for TH-57B/C developed at the Aviation Safety School, Monterey Calif., 1988

While trying to maintain tight section integrity on final to a confined-area landing, Dash 2, in a flight of two CH-46E helicopters, inadvertently descends slightly below his lead and lands hard in the landing zone.

The pilot of an SH-60 experiences vertigo on a night flight during a manual hover over water. He inadvertently enters a rapid vertical descent he couldn't arrest, even applying maximum collective.

What do these mishaps have in common? In each case, the helicopter descended into rotor downwash and entered what is commonly called the vortex ring state (VRS). This condition occurs when a rotary-wing aircraft inadvertently descends into its own vortices or "downwash." This situation disrupts the pressure differential that produces lift across the rotor blades. VRS also occurs when settling into the downwash of another aircraft, which commonly is called wake turbulence.

NATOPS manuals generally state VRS may occur during rates of descent greater than 800 fpm, at forward velocities less than 40 knots. These guidelines are extremely conservative and do not reflect differences in aircraft characteristics, nor do they account for the actual mechanism leading to the vortex ring state. Anyone who has tried to stand under a CH-53E in a hover can attest that the wind velocity (induced velocity) is far greater than from a Huey. This induced velocity is the speed of the air being "pumped" downward and is a function of disk loading (gross weight/rotor disk area) and air density.

A computational study by the U.S. Army Aviation Laboratory, in May 1971, developed vortex ring-envelope diagrams for the Vietnam-era Huey as a function of the aircraft's descent angle, horizontal speed, and induced velocity. This information subsequently was carried over to the primary training helicopters for naval aviation and may have been the genesis of the 800-fpm/40-knot guideline. At their respective normal operating gross weights and "Pensacola, Fort Rucker" standard sea-level conditions, the TH-57 and UH-1E/L yield VRS diagrams with approximately an 800-fpm upper threshold (Figure 1). The 40-knot guideline most probably was based on the inherent limiting characteristic of antiquated pitot-static, airspeed-sensing systems that are unreliable or erratic below 40 knots. For some reason, the 800-fpm/40-knot guideline was adopted by virtually every rotary-wing NATOPS manual without consideration for the vast range of gross weights and rotor-disk areas of modern helicopters. The guideline also ignored technological advances in low-airspeed sensing systems.

Template VRS diagrams were developed at the Aviation Safety School in the late 1980s for use by mishap investigators in their analysis. A diagram of choice quickly can be obtained by plugging in two known variables (gross weight and air density) for a given fixed-rotor-disk area (Figure 2). Interestingly, as your descent rate increases through the shaded region of the VRS diagram, the "downwash" flows up through the rotor system to an autorotative (engine out) profile that can be just as catastrophic from a low altitude. For example, look at the VRS diagram for a CH-53E at 55,000 pounds and standard sea level (Figure 3). The severe vortex ring state can be expected when reaching approximately 1,900 fpm at a horizontal speed of approximately 20 knots.

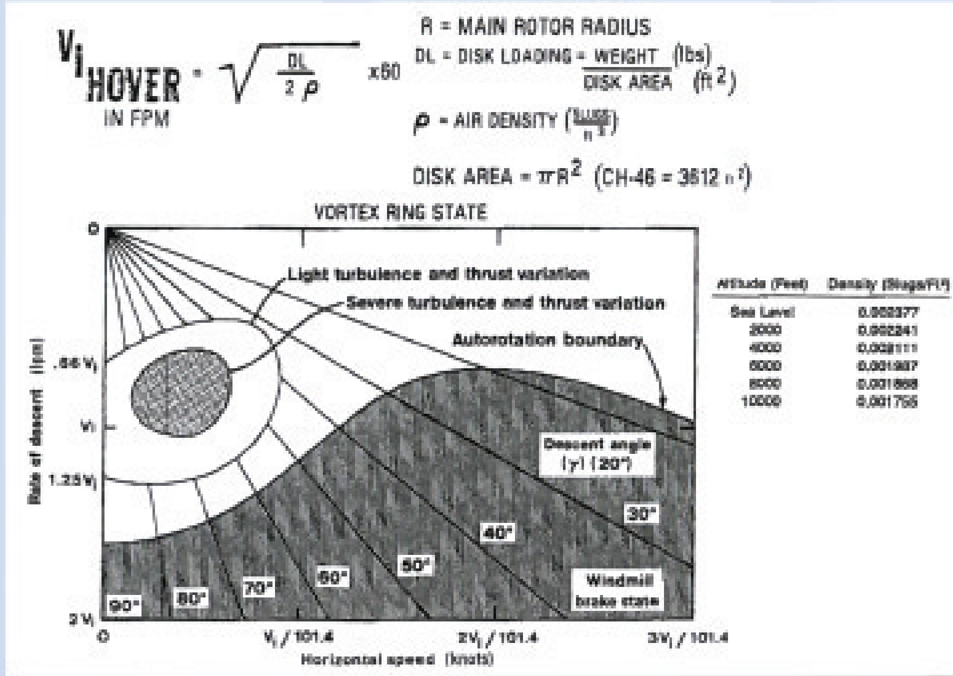

Fig. 2. Template Vortex Ring Diagram developed at the Aviation Safety School, Monterey Calif.,1988

These vortex ring-envelope diagrams can be derived computationally during the flight-planning phase. The diagrams clearly define the safe operating envelope for the mission and for the aircraft operating at any gross weight and atmospherics. In the rotary community, VRS diagrams can be as essential to mission accomplishment as excess power (Ps) diagrams are to the fixed-wing community. However, the first step in avoiding the vortex ring state is to know where it may be encountered on each and every flight.

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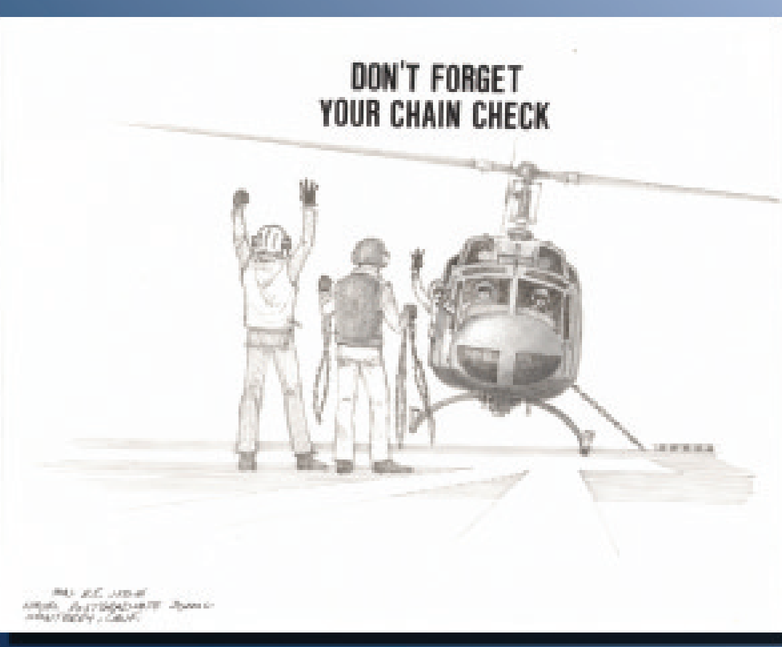

Fig. 3. Vortex Ring Diagram for CH-53E developed at the Aviation Safety School, Monterey Calif., 1988